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(54) Distance measuring apparatus and method.

(57) Apparatus for measuring distance has a magnetic strip (10), a magnetic pulse injection coil (12) and a 'barberpole' magnetoresistive sensor (11), both in operative association with the magnetic strip, one of the coil and the sensor being fixed relative to the strip and the other being movable along the strip, means for pulsing the injection coil, and means for timing the period t1 for a magnetic pulse to travel from the coil to the sensor so as to calculate the distance between them.

For temperature compensated measurement, measurements are made to or from both ends of the strip to the movable element.

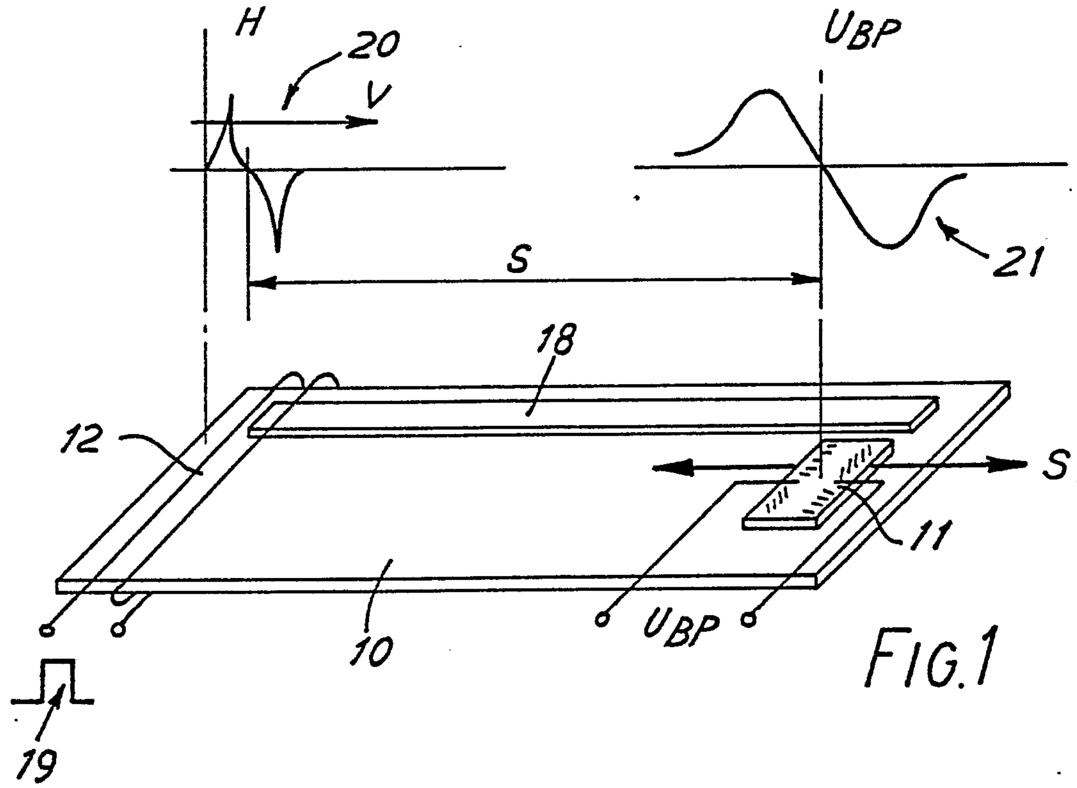

FIG.1

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Distance measuring apparatus and method

This invention relates to the measurement of distances, and to a method of doing so. It is particularly applicable to very accurate measurements, for example of the travel of a moving part of a machine.

It is often necessary to be able to measure very exactly (to an accuracy of less than 10 μm) the position of, for example, a piston of an operating cylinder, or of the tool head of a machine tool. The movement may be up to 2 metres. Various methods of doing this are known.

Commonly, a graduated glass rod is used with optical read-off means. Divisions are at 40 μm intervals and the resolution is 10 μm. But the rods are very expensive, easily broken, and become dirty. In addition, the tolerance to relative movement perpendicularly between glass rod and sensor means is low ($\pm$ 3/10 mm) and this can be a practical difficulty.

Laser interferometers are very accurate but too expensive for such applications.

A further method involves the use of a magnetic strip mounted on the bed of the machine and a position magnet on the movable part which defines its current position by altering the magnetic properties of the strip at that point. If a magnetic pulse (magnetostrictive vibration wave) is injected by a coil or a magnetic head at one end of the strip, an electrical pulse is generated in a coil extending along and around the strip at the moment the magnetic pulse reaches the position with altered magnetic properties. By timing the occurrence of this electrical pulse, a measure of the distance by the magnetic pulse is obtained.

The present invention aims to provide an improved and/or cheaper method of measuring distance.

Accordingly, the present invention proposes apparatus for measuring distance comprises a magnetic strip, a magnetic pulse injection coil and a 'barberpole' magnetoresistive sensor, both in operative association with the magnetic strip, one of the coil and the sensor being fixed relative to the strip and the other being movable along the strip, means for pulsing the injection coil, and means for timing the period t1 for a magnetic pulse to travel from the coil to the sensor so as to calculate the distance between them.

The distance is derived from the product of the measured time t and the known velocity v. The latter however is variable with temperature, so it is further possible to adopt a strategy to compensate for temperature. This involves the use of either two coils or two sensors at opposite ends of the strip, with respectively one sensor or one coil movable along the strip. By measuring the times t1, t2 or the pulse to travel from the movable sensor/coil to each of the coils/sensors, a formula can be used to relate these times to the reference length of the strip between the two coils/sensors, giving the required distance independently of temperature.

In order that the invention shall be clearly understood, several exemplary embodiments will now be described with reference to the accompanying drawings, in which:

Fig.1 illustrates the simplest form of the invention using one coil and one sensor;

Fig.2 shows a block circuit diagram; and

Fig.3 shows an apparatus using two fixed sensors and one movable injection coil.

The sensor used in this invention is called a 'Barberpole' element, and derives its name from the diagonal metallic stripes formed on a narrow permalloy strip. A permalloy strip included in an electrical circuit has a certain resistance; if subjected to a magnetic field the resistance changes. The (magnetoresistive effect). The metallic stripes of the element improve and linearise the effect. Such an element can detect the passage of a magnetic pulse through a magnetic medium if the magnetic field of the pulse embraces the element.

An even more definite and quantifiable effect is obtained if four such 'barberpole' elements are connected in a bridge circuit. The principles of such sensors is described fully in the Technical Information Leaflet No. 840323 of Valvo (Unternehmungsbereich Bauelemente der Philips GmbH, Hamburg).

As seen in Figure 1, an amorphous metal (permalloy) strip 10 is fixed to the bed of the machine of which the movable member e.g. a piston (not shown), is to have its position monitored. Attached to the piston is a barberpole bridge 11. The strip 10 is long enough that the barberpole bridge 11 remains in association with it over its full path of movement, illustrated by the arrows. At one end, the strip 10 has a pulse injection coil 12.

A voltage pulse 19 is applied to the injection coil 12. This produces a sudden magneto-accoustic pulse 20 in the strip 10 which propagates along the latter at a speed V.

Once the pulse reaches the barberpole bridge 11, a voltage reversal 21 appears across its terminals, The time elapsed t between 20 and 21 is proportional to the distance S between coil 12 and bridge 11.

However, as pointed out at the start, a change of temperature reduces the accuracy of this measurement, and it is an advantage to compensate for this.

For this purpose it is necessary to know the temperature, and therefore a serpentine temperature sensor 18 may be deposited along the strip 10 as a thin film. This allows determination of the mean temperature, and thus calculation of the temperature expansion of the strip 10. From this, corrected value of s can be calculated allowing for the expansion.

An alternative solution to this problem is illustrated in Fig.3. The apparatus is similar to Fig.1, but in this case it is the injection coil 12 which moves with the piston and two barberpole bridges 11 are fixed to the strip 10. The injection coil 12 is shown as wound around the strip 10, but for it to be movable it must in practice be wound on a core attached to the piston. Further, the strip is terminated at each end with its characteristic impedance 15. This is to eliminate reflections of the magneto-acoustic pulse when it reaches the end of the strip.

The calculation of the distance S1 of the coil 12 from one end of the strip is then undertaken as follows: The total (known) length S has an extension of $\Delta S(\theta)$ at temperature θ°, made up of the extension $\Delta S1(\theta)$ of S1 to the left of the coil 12, and $\Delta S2(\theta)$ of S2 to the right.

When a pulse is initiated in injection coil 12, it requires the times t1 and t2 measured as in Fig.1 to travel the distances S1 and S2 to the respective ends of the strip 10. These times are in reality of magnitude $t1 + \Delta t1(\theta)$ and $t2 + \Delta t2(\theta)$. The measurements are then employed as follows.

The temperature extension is:

$$\Delta S\theta = [S1(\theta) + S2(\theta)] - S \qquad (1)$$

Moreover:

$$S1(\theta) = S1 + S1 . \frac{\Delta S(\theta)}{S} \qquad (2)$$

Solved for S1 :

$$S1 = \frac{S1(\theta)}{1 + \frac{\Delta S(\theta)}{S}} \qquad (3)$$

Inserting (1) in (3)

$$S1 = \frac{S1(\theta)}{S1(\theta) + S2(\theta)} \cdot S \sim \frac{t1(\theta)}{t1(\theta) + t2(\theta)} \cdot S \qquad (4)$$

Thus, measurement of the actual values of $t1(\theta)$ and $t2(\theta)$, without discrimination as to the value of $t1(\theta)$ or $t2(\theta)$ gives an exact value of s1 from equation (4), S being known. There is thus no need to know the pulse velocity V, or its corrected value $V(\theta)$ at temperature θ°.

There are various alternative arrangements possible since the coil and the barberpole bridge are in effect interchangeable. Further, if the arrangement of Fig.1 is adopted, a reflected wave may be employed derived from a single pulse to give times t1 (as already described) and t1 + 2t2 for the pulse reflected from the far end of the strip. Equation 4 is then used as for Fig.3 .

In order to take account of the value of θ, in calculating s by the simplest method, the serpentine temperature sensor 18 may be used to provide the value of θ.

Figure 2 illustrates a block diagram of a circuit suitable to provide a display reading the distance s directly.

Claims

1. Apparatus for measuring distance comprising a magnetic strip (10), a magnetic pulse injection coil (12) and a 'barberpole' magnetroresistive sensor (11) both in operative association with the magnetic strip, one of the coil and sensor being fixed relative to the strip and the other being movable along the strip, means for pulsing the injection coil, and means for timing the period t1 for a magnetic pulse to travel from the coil to the sensor so as to calculate the distance between them.

2. Apparatus as claimed in claim 1, wherein the magnetic strip (10) carries means (18) to measure the

mean temperature along its length.

3. Apparatus as claimed in claim 2 wherein said means comprises a serpentine conductive resistor having a high temperature coefficient of resistance from which said temperature can be measured.

4. Apparatus as claimed in any preceding claim, wherein in addition the timing means measures the time 2t2 for the magnetic pulse to travel along the remaining distance along the strip, and back again after reflection from an end thereof.

5. Apparatus as claimed in any of claims 1,2 or 3 wherein a further coil or sensor is provided to allow measurement of t1 and t2 from the coil or sensor movable along the strip to the sensors or coils fixed at the ends of the strip.

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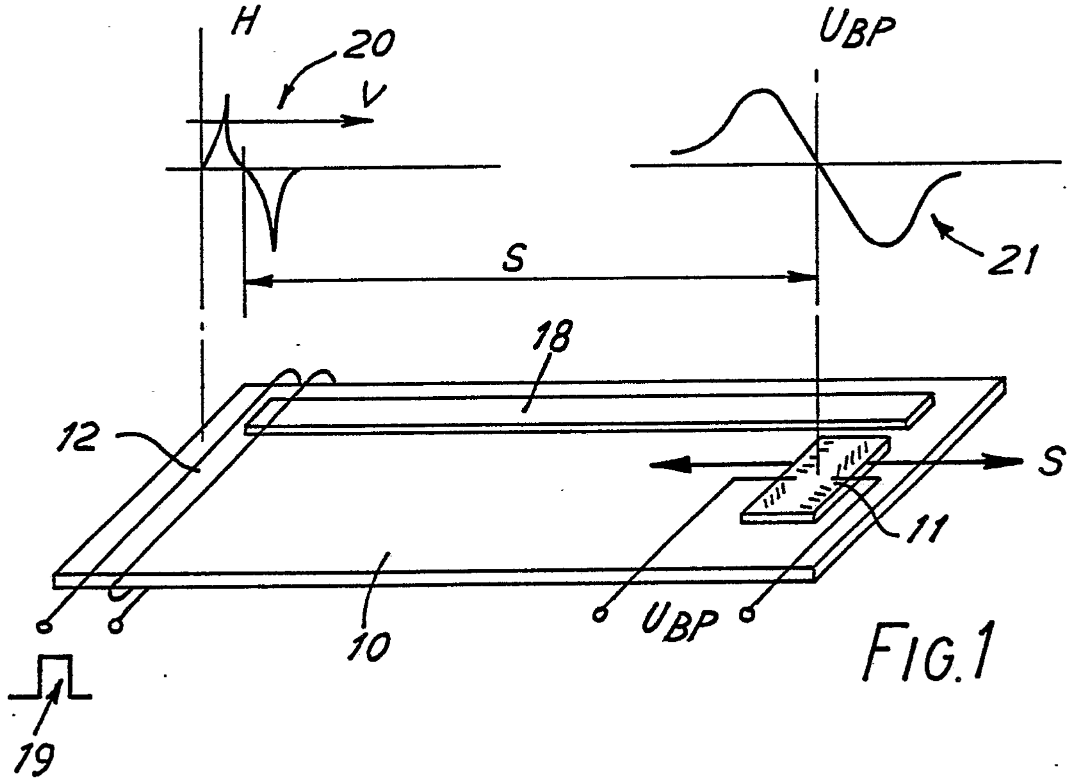

FIG.1

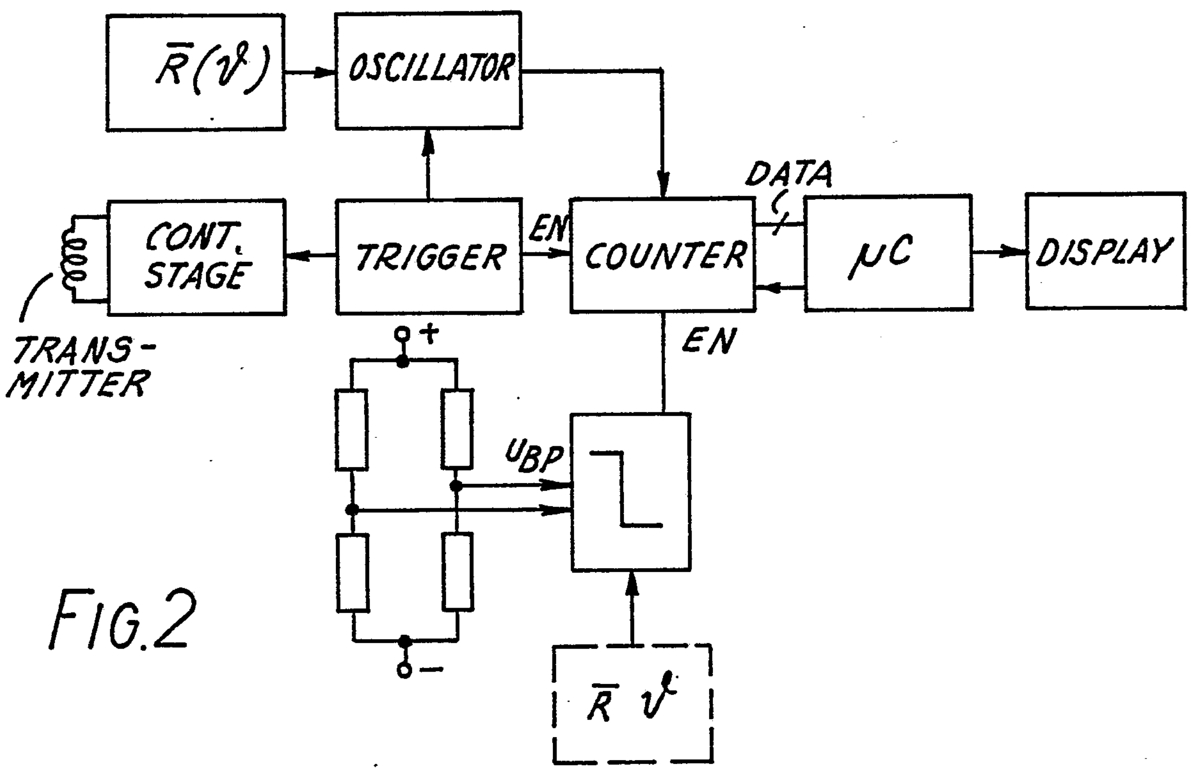

FIG.2

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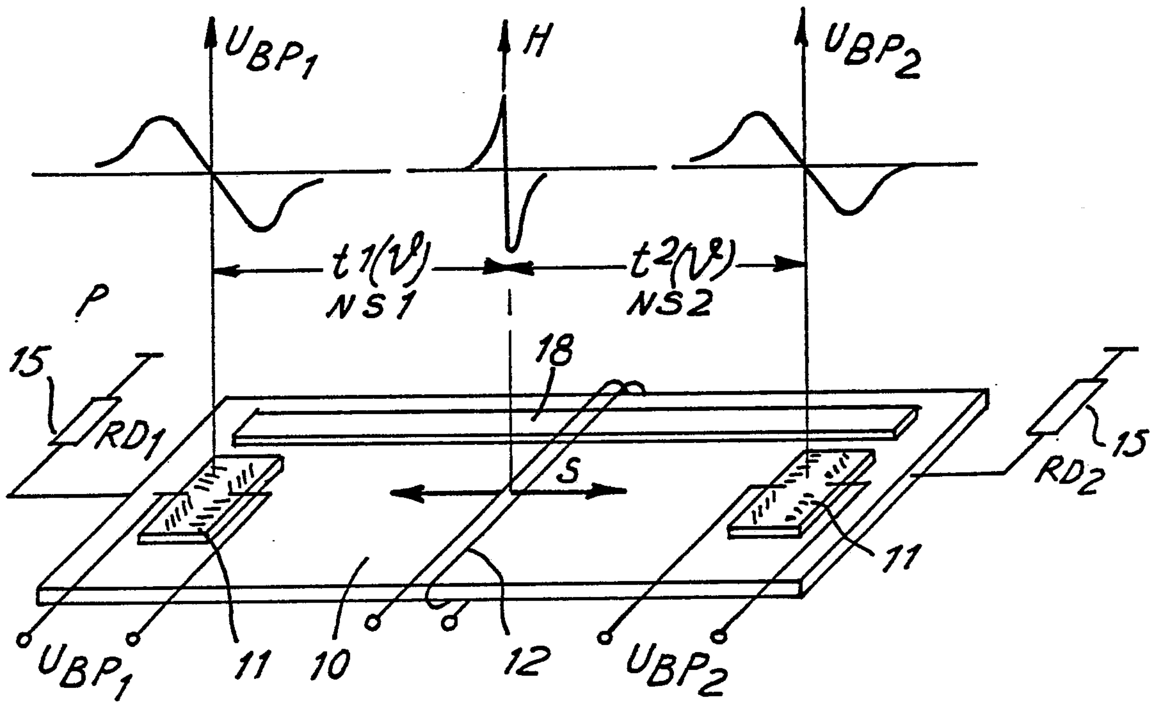
U_{BP_1}
H
U_{BP_2}
t1(ϑ)
NS1
t2(ϑ)
NS2
P
15
RD1
18
S
RD2
15
11
U_{BP_1}
11
10
12
U_{BP_2}

FIG. 3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 88 11 7100

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.3)
Y	ELECTRONIC COMPONENTS & APPLICATIONS, vol. 5, no. 3, June 1983, pages 148-153, Eindhoven, NL; U. DIBBERN et al.: "The magnetoresistive sensor - a sensitive device for detecting magnetic field variations" * Whole document *	1,4,5	G 01 D 5/48 G 01 D 5/16
Y	GB-A-2 016 694 (YOKOGAWA) * Abstract; figures; page 1, line 111 - page 2, line 22 *	1,4,5	
A	IEEE TRANSACTIONS ON MAGNETICS, vol. MAG-16, no. 5, September 1980, pages 693-694, IEEE, New York, US; T.K. WORTHINGTON et al.: "A magnetoacoustic position sensor" * Page 694, lines 1-10 *	2	
A	PATENT ABSTRACTS OF JAPAN, vol. 9, no. 262 (P-398)[1985], 19th October 1985; & JP-A-60 111 917 (HITACHI SEISAKUSHO K.K.) 18-06-1985 * Abstract *	2	**TECHNICAL FIELDS SEARCHED (Int. Cl.3)** G 01 D H 03 H

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	06-06-1989	LLOYD P.A.

CATEGORY OF CITED DOCUMENTS

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